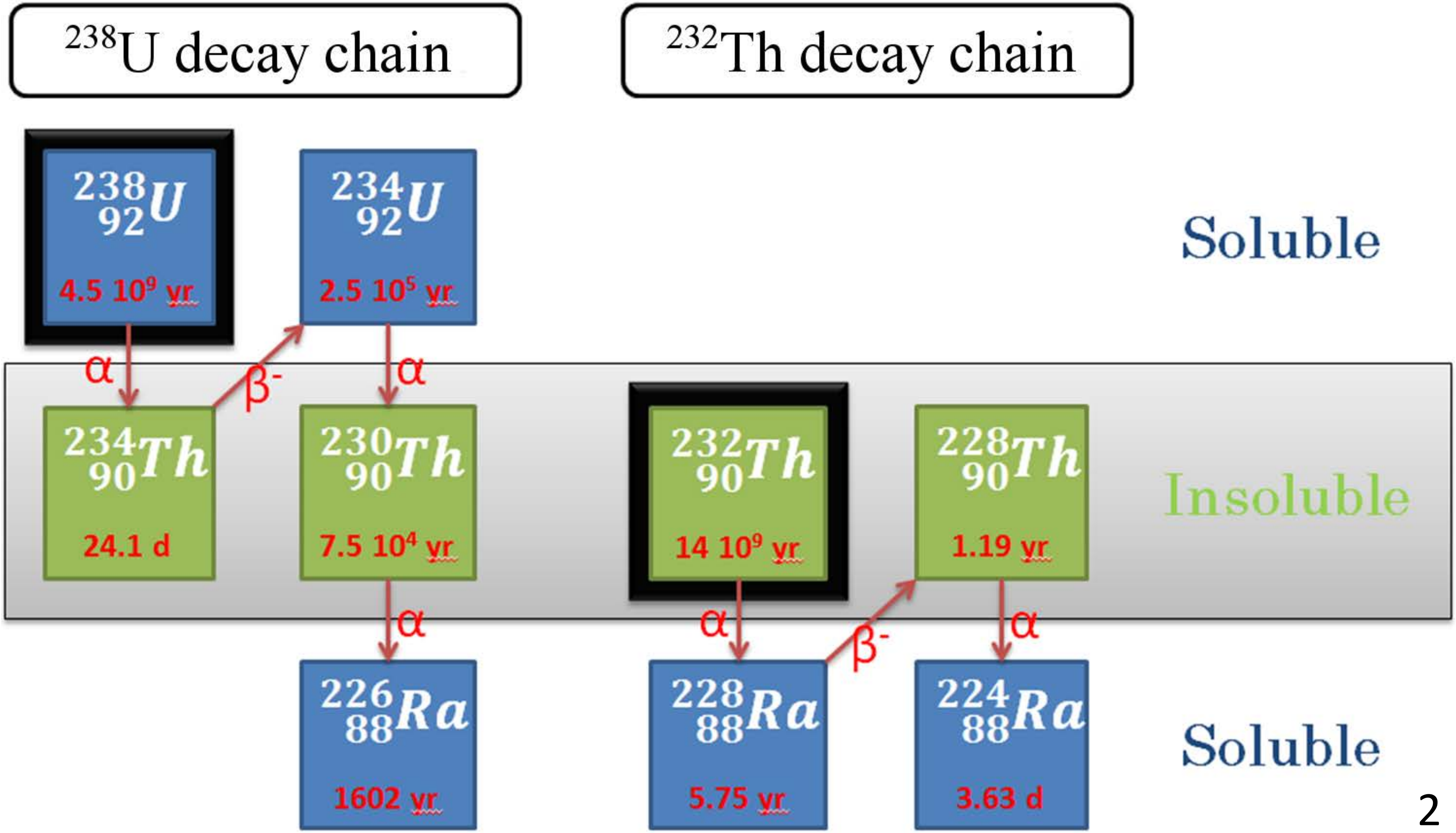
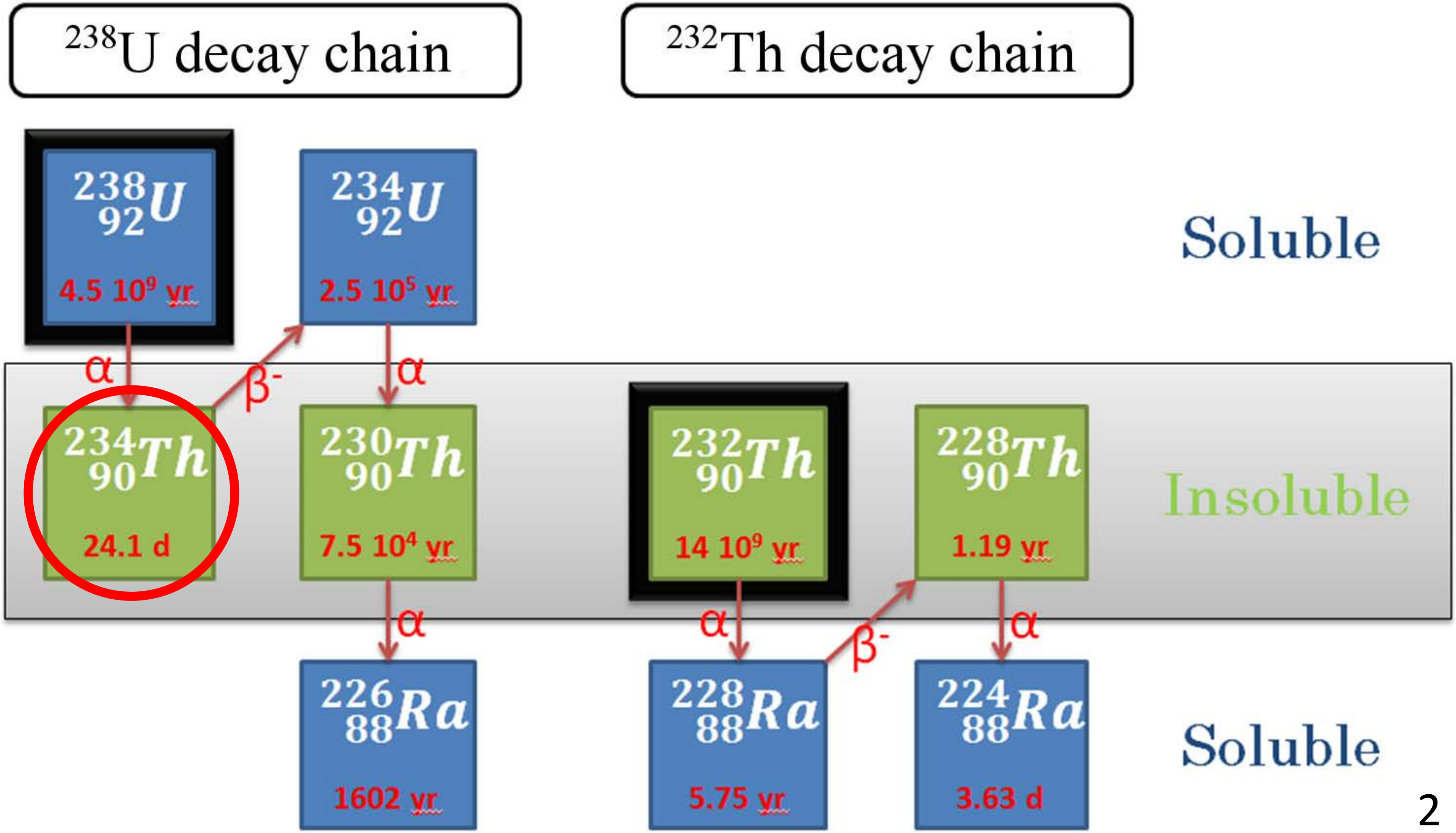
Estimating Thorium-234 Partition Coefficients by Inverse Modeling

<u>Guillaume LE GLAND</u> (LEMAR, IUEM, Brest)
Olivier AUMONT (LOCEAN, UPMC, Paris)
Laurent MÉMERY (LEMAR, IUEM, Brest)

Thorium-234: a heavy radio-isotope



Thorium-234: a heavy radio-isotope



Thorium-234: a proxy of the biological pump

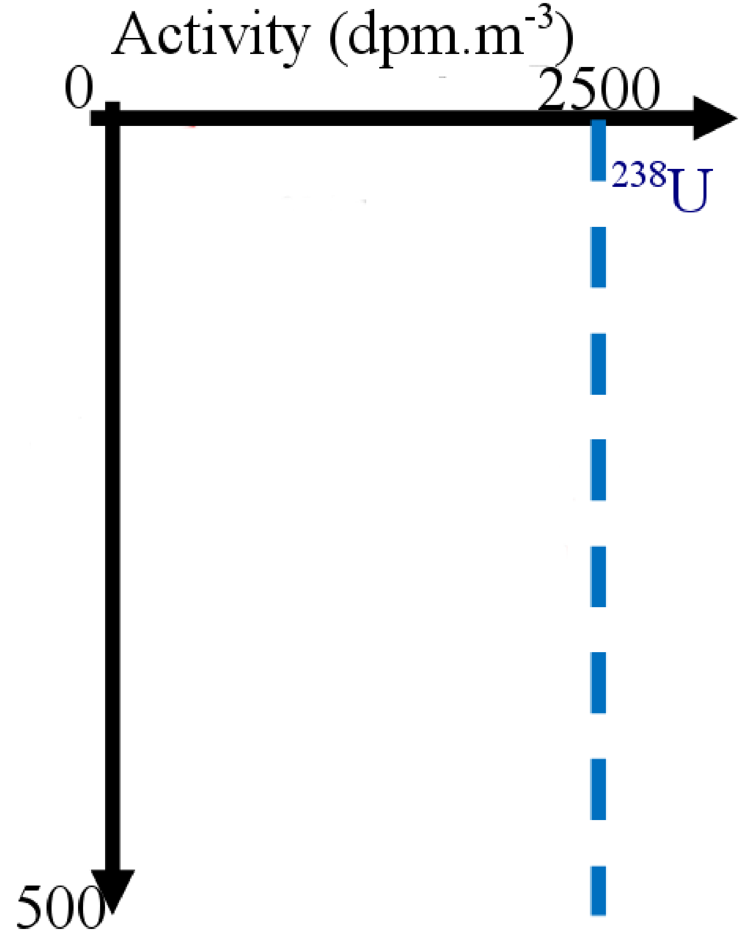
Sources :

- ^{238}U decay (λU)

Sinks :

- ^{234}Th decay $(-\lambda Th)$

$$\frac{\partial Th}{\partial t} = \lambda(U - Th) \qquad + transport$$



Thorium-234: a proxy of the biological pump

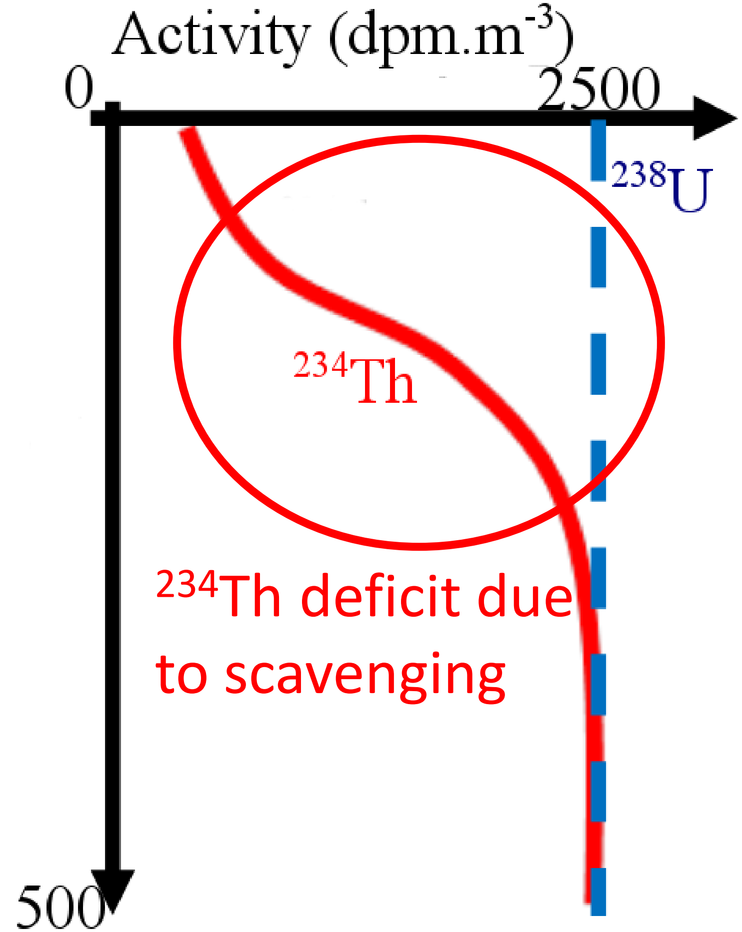
Sources :

- ^{238}U decay (λU)

Sinks :

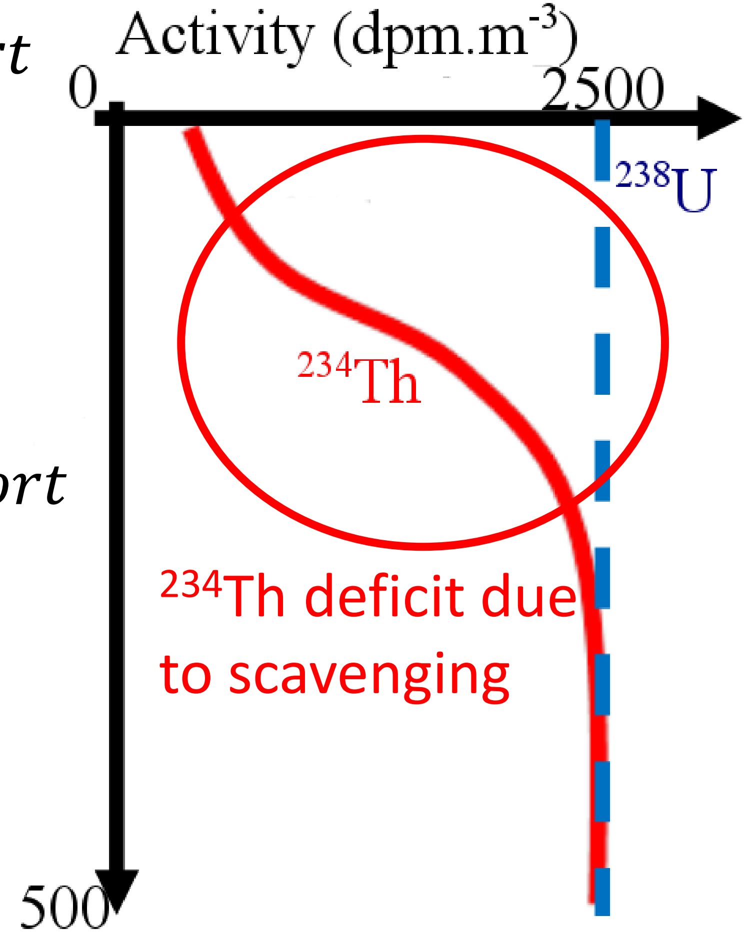
- ^{234}Th decay $(-\lambda Th)$
- Scavenging by particles $(-E_{Th})$

$$\frac{\partial Th}{\partial t} = \lambda(U - Th) - E_{Th} + transport$$



Thorium-234: a proxy of the biological pump

$$\frac{\partial Th}{\partial t} = \lambda(U - Th) - E_{Th} + transport$$

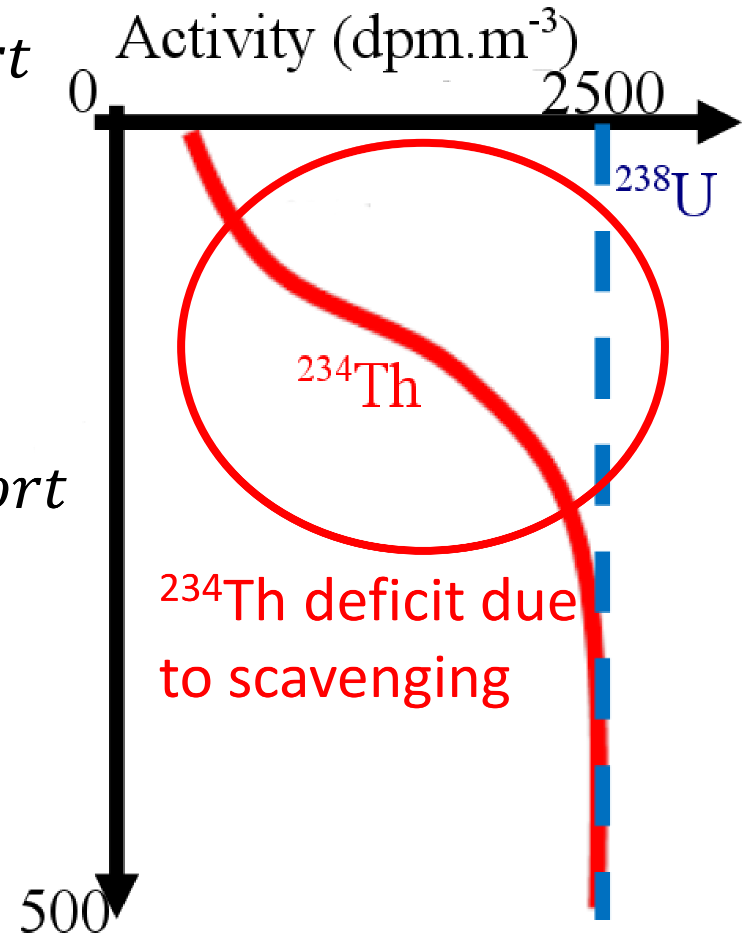


^{234}Th export at depth z :

$$E_{Th}(z) = \int_0^z \lambda(U - Th) - \int_0^z \frac{\partial Th}{\partial t} + transport$$

Thorium-234: a proxy of the biological pump

$$\frac{\partial Th}{\partial t} = \lambda(U - Th) - E_{Th} + transport$$



^{234}Th export at depth z :

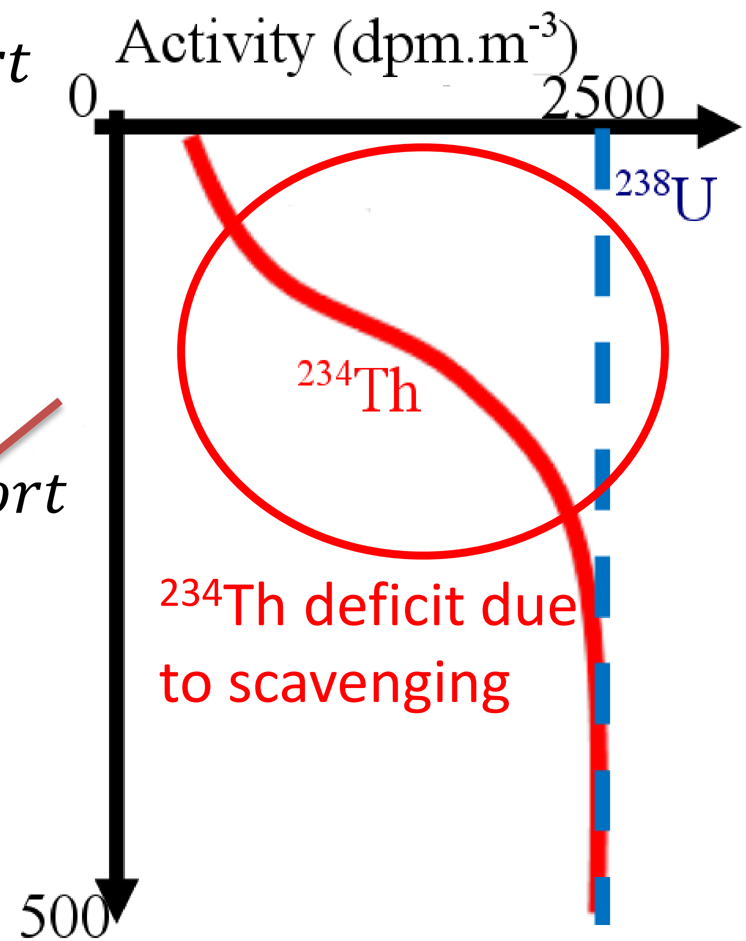
$$E_{Th}(z) = \int_0^z \lambda(U - Th) - \cancel{\int_0^z \frac{\partial Th}{\partial t}} + transport$$

Thorium-234: a proxy of the biological pump

$$\frac{\partial Th}{\partial t} = \lambda(U - Th) - E_{Th} + transport$$

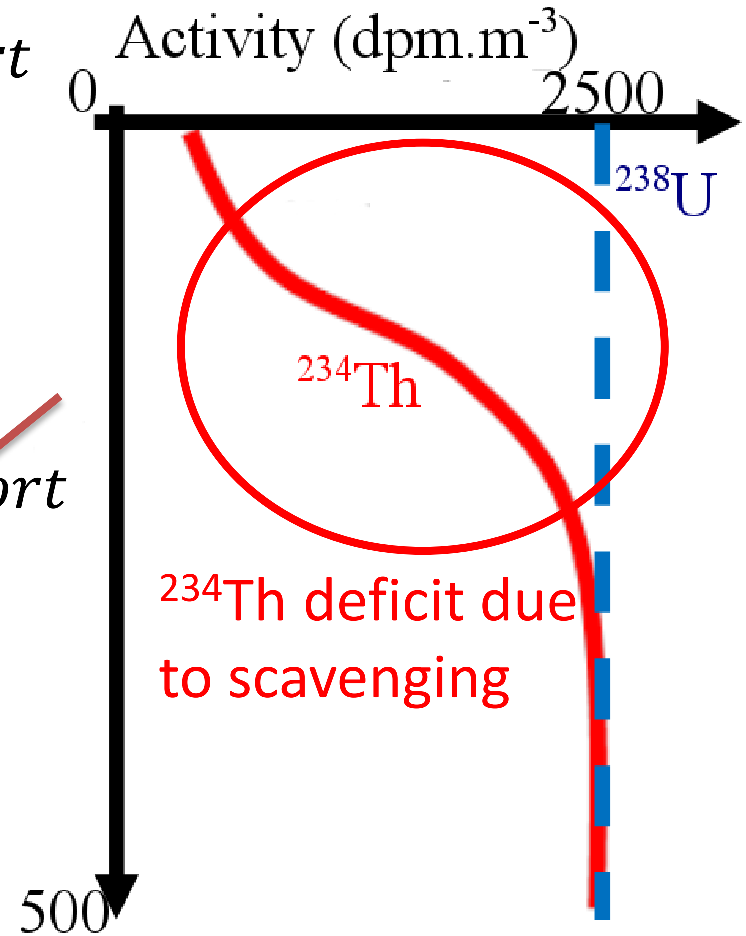
^{234}Th export at depth z :

$$E_{Th}(z) = \int_0^z \lambda(U - Th) - \cancel{\int_0^z \frac{\partial Th}{\partial t}} + \cancel{transport}$$



Thorium-234: a proxy of the biological pump

$$\frac{\partial Th}{\partial t} = \lambda(U - Th) - E_{Th} + transport$$



^{234}Th export at depth z :

$$E_{Th}(z) = \int_0^z \lambda(U - Th) - \cancel{\int_0^z \frac{\partial Th}{\partial t}} + \cancel{transport}$$

Carbon export :

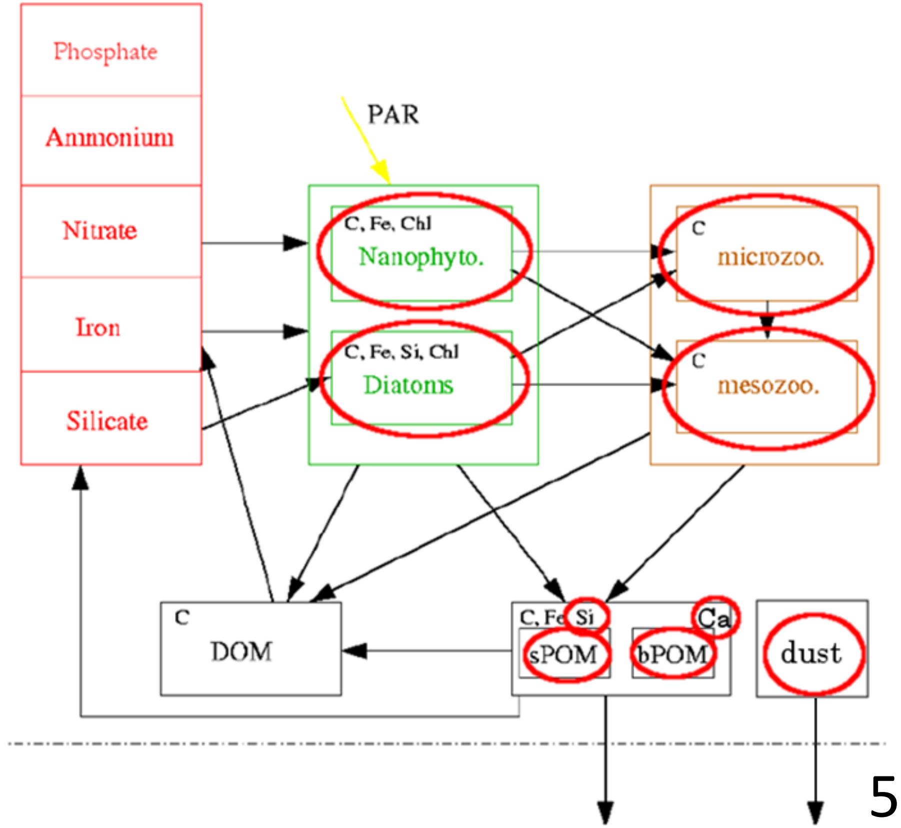
$$E_C(z) = (C{:}Th)E_{Th}(z)$$

What $(C{:}Th)$? Often the one of large particles

Thorium-234: a proxy of the biological pump

Partition coefficient for particle type p:

$$\boldsymbol{K_p^d} = \frac{[Th]_p}{C_p[Th]_{diss}}$$



5 different $\boldsymbol{K_p^d}$:

- Plankton (4 types)
- Small POC (Particulate Organic C)
- Large POC / calcite
- Biogenic silica
- Lithogenic dust

Objective 1 : Estimate the partition coefficients of ^{234}Th for different particle types (by inverse modeling)

Inverse technique

Inverse modeling is made of three elements:

1) « Direct » model

2) Observations

3) Inverse algorithm

Inverse technique

Step 1: Direct model (global)

$$\frac{\partial Th}{\partial t} = \lambda(U - Th) - E_{Th} + transport$$

Transport:

- Advection / Diffusion from **NEMO-OPA** (OGCM)

Export:

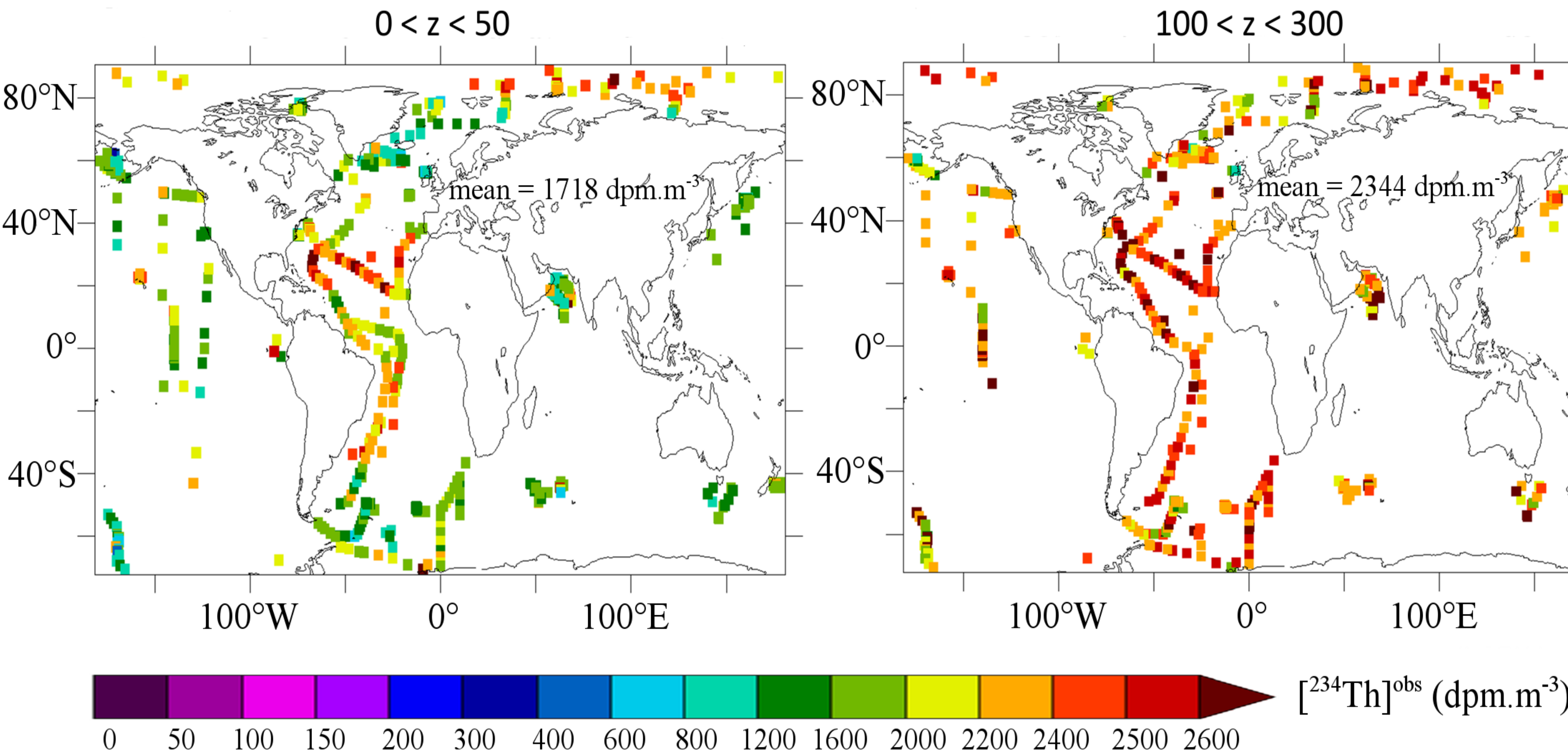
- Particle concentrations from **PISCES**
- Constant partition coefficients ($\boldsymbol{K_p^d}$) for each particle type (≈ instantaneous equilibrium)

✓ Seasonal cycle

X No interannual variation

Inverse technique

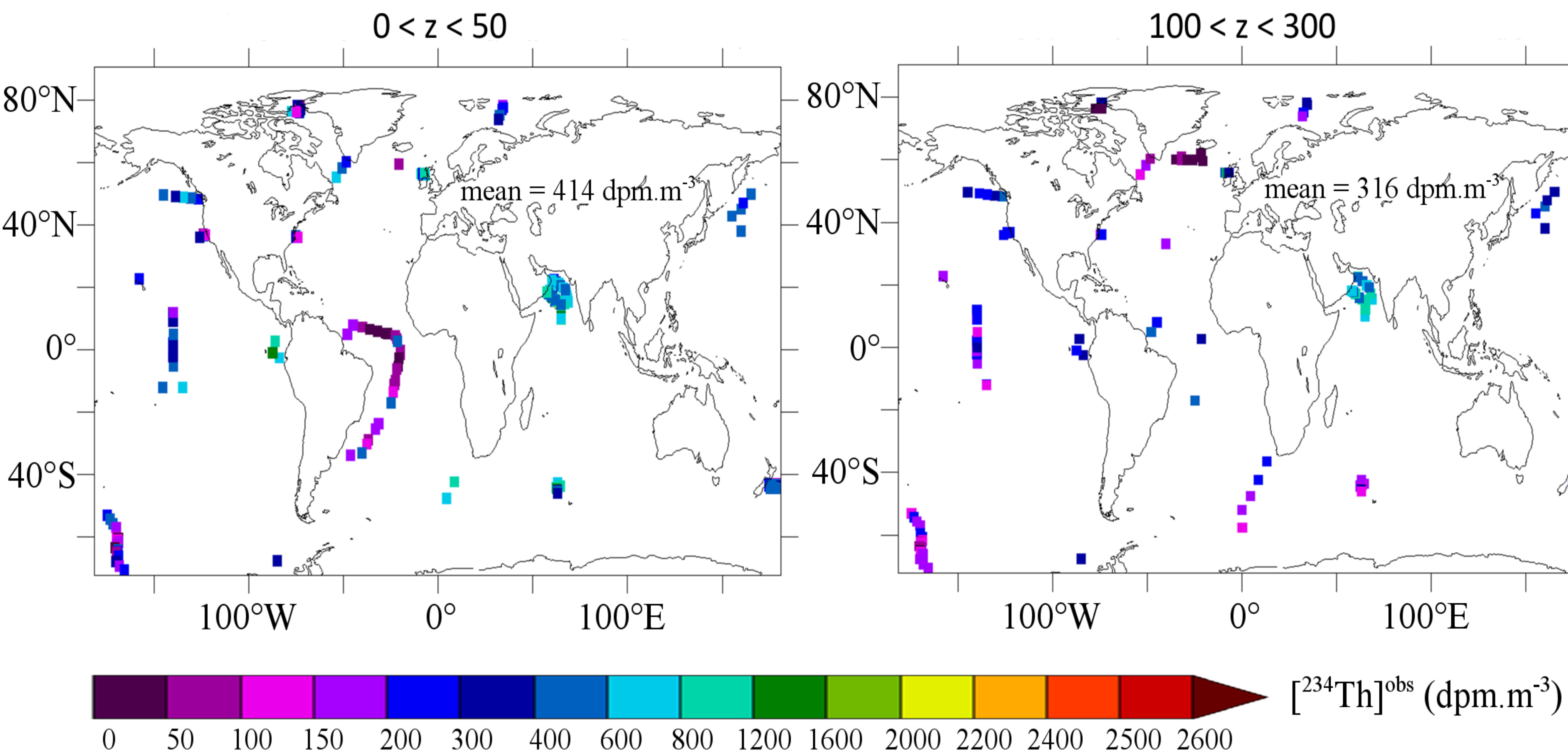
Step 2: Observations



Total ^{234}Th …

Inverse technique

Step 2: Observations



Total ^{234}Th … and particulate ^{234}Th

Inverse technique

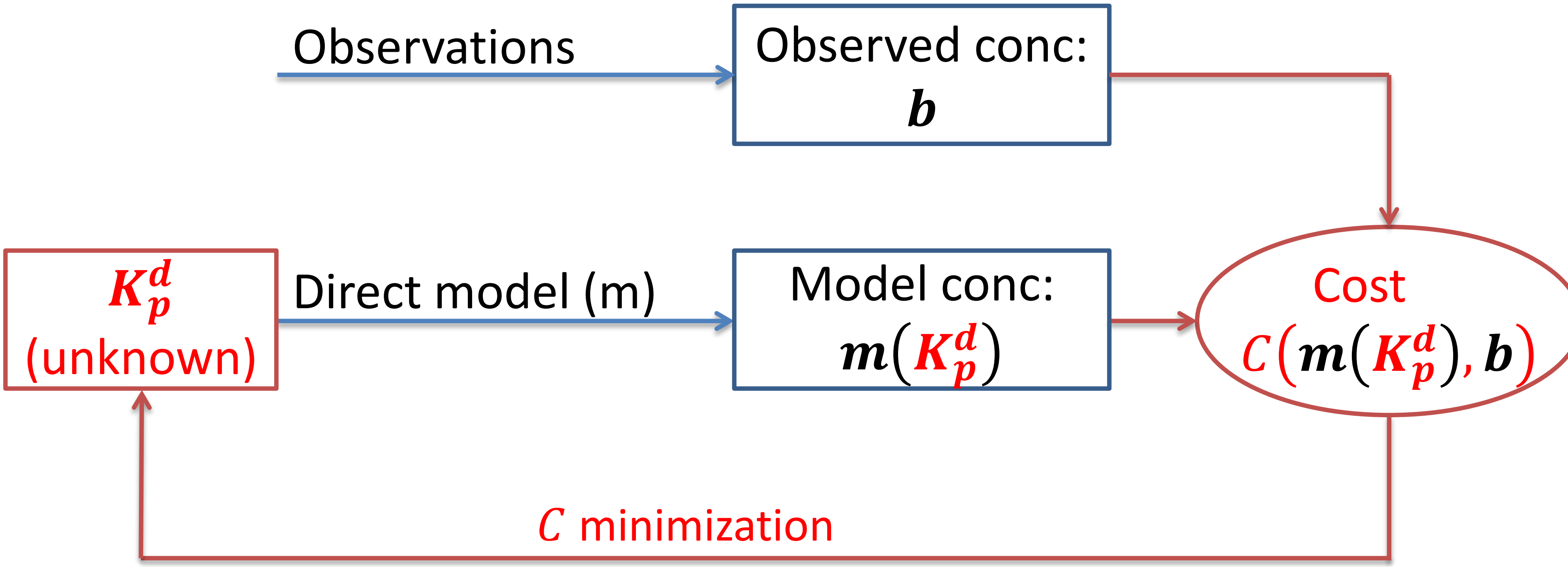
Step 3: Inverse algorithm

Observations → Observed conc: $\boldsymbol{b}$

$\boldsymbol{K_p^d}$ (unknown) → Direct model (m) → Model conc: $\boldsymbol{m}(\boldsymbol{K_p^d})$

Inverse technique

Step 3: Inverse algorithm



- Least squares:

$$C(\boldsymbol{K_p^d}) = \sum_i \left(m_i^{tot}(\boldsymbol{K_p^d}) - b_i^{tot}\right)^2 + \sum_j \left(m_j^{par}(\boldsymbol{K_p^d}) - b_j^{par}\right)^2$$

Inversion results

Particles	K^d (x 10^6)
plankton	1,80 – 2,07
small POC	3,93 – 4,32
bPOC / cal	1,90 – 2,03
silica	1,29 – 1,44
dust	14,0 – 16,7

Inversion results

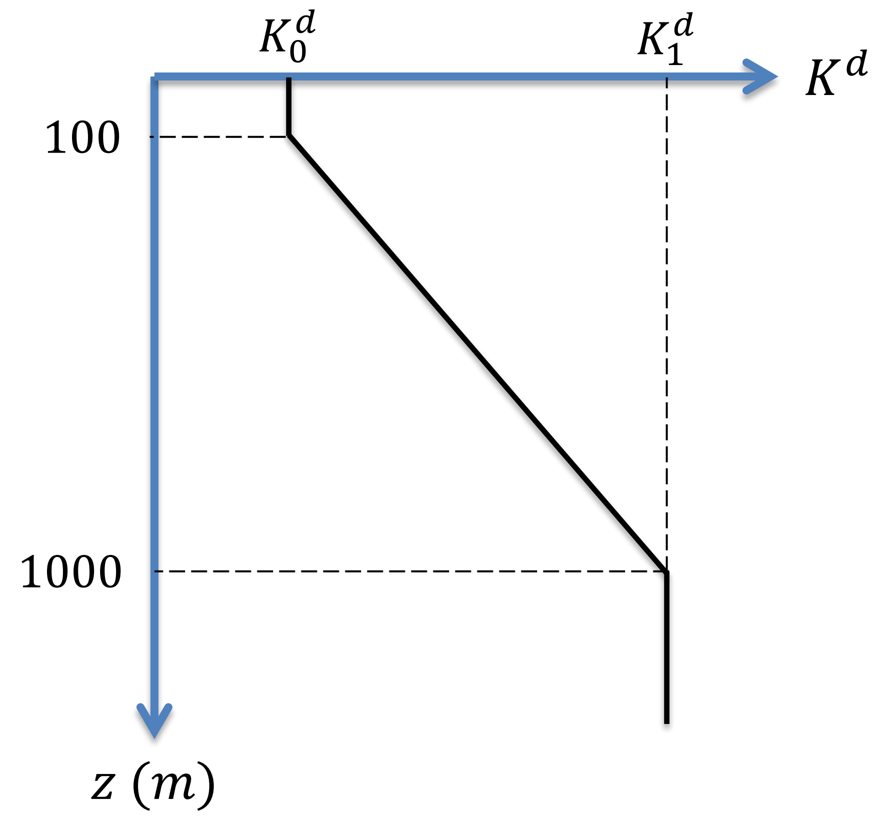
Depth	Mean residual (mod - obs)	
	$\boldsymbol{Th^{tot}}$	$\boldsymbol{Th^{par}}$
0 < z < 50	+ 54	+ 35
50 < z < 100	+ 62	+ 11
100 < z < 300	+ 84	- 41
300 < z < 1000	+ 92	- 121

Inversion results

Variable partition coefficient

Constant K_p^d ≈ instantaneous equilibrium

Variable K_p^d ≈ Sinking particules adsorb ^{234}Th continuously



Inversion results

Particles	Partition coefficient ($\times 10^6$) Constant	$z < 100$m	$z > 1000$m
plankton	1,80 – 2,07	1,26 – 1,53	
smal POC	3,93 – 4,32	4,73 – 5,14	10,8 – 17,5
bPOC / cal	1,90 – 2,03	1,70 – 1,84	18,0 – 20,9
silica	1,29 – 1,44	1,07 – 1,23	8,1 – 11,4
dust	14,0 – 16,7	12,0 – 14,5	49 – 107

Inversion results

Depth	Constant K_p^d Mean residual (mod – obs) $\boldsymbol{Th^{tot}}$	Constant K_p^d Mean residual (mod – obs) $\boldsymbol{Th^{par}}$	Variable K_p^d(z) Mean residual (mod - obs) $\boldsymbol{Th^{tot}}$	Variable K_p^d(z) Mean residual (mod - obs) $\boldsymbol{Th^{par}}$
100 < z < 300	+ 84	- 41	+ 17	+ 7
300 < z < 1000	+ 92	- 121	+ 30	+ 21

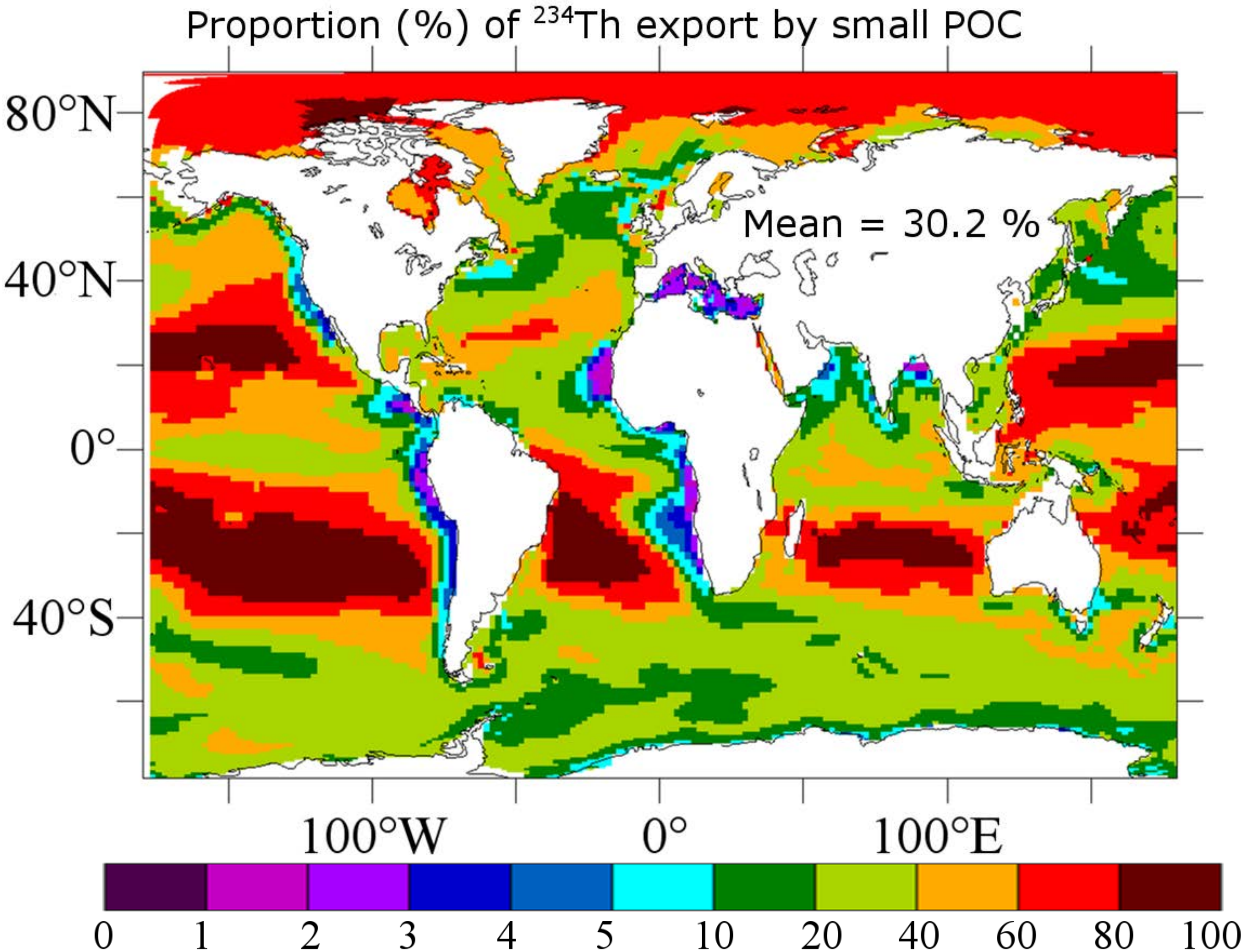
✓ Bias reduction

Objective 1 : Estimate the partition coefficients of ^{234}Th for different particle types (using an inverse technique)

Objective 2 : Quantify the biases associated with some ordinary simplifications of ^{234}Th-based biological carbon pump estimates

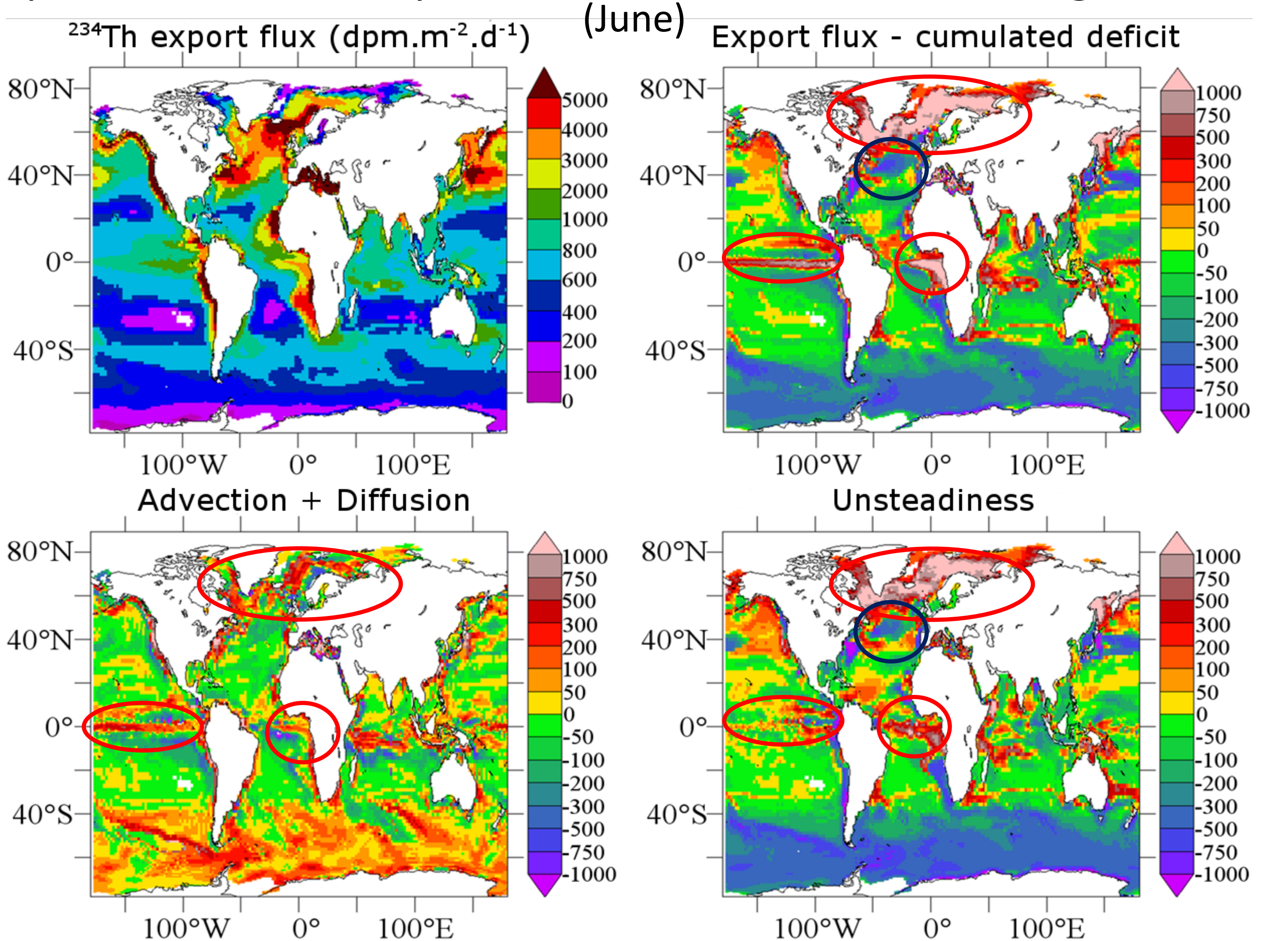
Biases in carbon pump estimates

Assumption 1: Export by large particles alone ?



Biases in carbon pump estimates

Assumptions 2 & 3 :Steady state? Advection / diffusion neglectable ?



Main results

1) 5 K_p^d estimated

- silica < plankton < large POC / calcite < small POC < dust
- Only as good as the (direct) particle model !

2) Large vertical variation in K_p^d (applies to other scavanged metals)

3) Steady state, no transport and export by large particles alone can bias biological carbon pump estimates by up to a factor 2